Vertical Plasma Extent above the Lunar Surface Derived from Interference Pattern of Auroral Kilometric Radiation

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1. Introduction

The lunar atmosphere is extremely tenuous compared to the Earth's atmosphere and circumlunar plasma produced by photoionization is considered to be less dense than solar wind. Nevertheless, it was reported that 500 to 1000 cm^{-3} electron densities were observed at altitudes of 5 to 10 km near the sunrise terminator by the Soviet Luna 19 and 22 in the 1970s. The high-density layer was interpreted to be the lunar ionosphere. This result remains controversial, however, because the observed large density is difficult to explain theoretically without magnetic shielding from the solar wind. Observation data on the circumlunar plasma were very scarce and the existence of the lunar ionosphere had been neither experimentally proved nor disproved while many researchers have tried to explain its generation mechanism. The Japanese Kaguya project provided the opportunity to diagnose the vertical extent of the circumlunar plasma through a new approach using interference patterns of natural plasma waves in addition to the conventional radio occultation experiment. Although the radio occultation technique is profoundly influenced by the earth's ionosphere, the newly-developed method can sensitively detect plasma layers regardless of the conditions of the earth's ionosphere. In the present study, using the new method, we estimated the vertical electron densities at the terminator regions and examined whether the high-density layer actually existed or not.

2. Methodology

The natural plasma wave receiver (NPW) instrument, which are subsystems of the lunar radar sounder (LRS) [1] on board the lunar orbiter KAGUYA, observed auroral kilometric radiation (AKR) propagating from the Earth. The dynamic spectra of the AKR sometimes exhibit a clear interference pattern because the AKR is reflected on the lunar surface and superposed on the directly arrived AKR. Such interference patterns arose from a difference of path lengths between the direct and reflected AKRs. In cases where the dense plasma vertically distributes along the altitude of the moon like in the Luna measurements, the AKR should be reflected at an altitude where the apparent plasma frequency corresponds to the wave frequency, and the path length of the reflected wave should be shortened. Besides, the group velocity of the wave should slow as it passes through the dense plasma. In this way, the interference pattern is determined by the plasma existing between the orbit of KAGUYA and the lunar surface. Using the ray tracing technique, locations of reflection points can be determined under a geometric optics approximation by providing electron density profiles and the phase difference between direct and reflected AKRs can be derived [2]. Then, by using a model-fitting technique, we can derive the vertical electron density profile which reproduces the observed interference pattern most accurately with the ray tracing technique.

3. Results

We first examined the validity of the developed method by using several types of computer-generated vertical density profiles including the profiles observed by the Luna and confirmed that they could be approximately reconstructed by a simple analytical model. Then, we applied the method to twenty three interference patterns which had been observed near the terminator regions. It should be noted that, under conditions of the analyzed cases, the minimum electron density required for the detection is fairly low (a few tens of electrons /cm^3). As a result, all the estimated density profiles had no high-density layers. In two cases, the reflection points were located at a magnetic anomaly where a strong remnant magnetic field existed and were not affected by the solar wind. Even in such stable magnetic field conditions, vertical plasma extents were not discovered. Solar zenith angles (SZA) of the analyzed cases are between 68 and 100 degrees and this range overlaps those of the Luna experiments. Considering such conditions, the results seem to contradict the Luna measurements. In the presentation, we would like to discuss some possible explanations for the difference of the Luna and KAGUYA results.

References

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